2.—Landforms and soils of southwestern Australia

By M. J. Mulcahy[1]

Abstract

The landforms of southwestern Australia are outlined as a basis for a description of the distribution of the extremely weathered materials and superficial deposits on which the soils are formed. While soils on younger landscape elements change predictably with climatic change, a major factor controlling soil distribution is the degree of erosional modification of the leached and deeply weathered profiles associated with the older landforms which are extensively preserved, both in higher rainfall areas and the arid interior. The significance of the soil patterns and their characteristics are briefly discussed.

Introduction

The area dealt with in this paper lies to the south of the latitude of Geraldton, and extends from the west coast eastwards to include Kalgoorlie and Esperance. It forms part of the Great Plateau of Western Australia (Jutson, 1914) consisting of a stable Archaean shield, characterized by low relief, extending over the Mesozoic rocks of the Perth basin in the north west, all flanked by narrow coastal plains of younger sediments.

It is part of the landscape described by Hills (1961) an "ageless and undatable old land". Woolnough (1927) associated the widespread deep weathering with peneplanation, and Prescott (1931) pointed out the occurrence of leached, acid, lateritic soil materials extending from the humid coastal areas to the now arid interior.

Early soil maps such as that of Prescott (*loc. cit.*) and later Stephens (1961) influenced by the Russian school of pedologists, emphasized climatic zonation, and south-western Australia tended to be shown with soil boundaries parallel to the isohyets. Teakle's regional soil classification, published in 1938, and subject to the same influence, left out of account the "azonal" lateritic soils, dealing mainly with the more fertile soils of the younger landscape elements. This was good sense at that time since the technology necessary for agricultural development of the lateritic soils, including the use of minor elements, was only just then becoming available, and the use of soils in the higher rainfall areas as a bauxite ore was still some years away. A later compilation in the form of the Atlas of Australian Soils (Northcote *et al.*, 1967), based on much more detailed information, indicates a strong relationship between soil distribution and drainage pattern as well as climate, while Mulcahy *et al.* (1972) have shown that geological structure and the extent of drainage rejuvenation are also important.

[1]Division of Land Resources Management, CSIRO, Wembley, Western Australia.

Stephens (1946), in his classical paper on pedogenesis following the dissection of lateritic regions by downcutting streams rejuvenated after uplift, suggests a fairly simple picture of lateritic materials preserved on peneplain remnants and removed from the slopes below. Playford (1954), on the other hand, pointing out that lateritic materials are frequently found at many levels in the one landscape, and assuming laterite formation during some single period in the past, concluded that this must therefore have been postuplift.

Subsequent investigations in soil-landform relationships, on which this account is based, show that the situation is probably rather more complex than the early workers believed. It appears that laterite profiles, including both surface ferruginous horizons and underlying pallid zones (Walther, 1915), are to be found extensively in a wide range of topographic situations, ranging from piedmont deposits of the Swan Coastal Plain (McArthur and Bettenay, 1960), and older alluvial terraces in well-incised valleys such as that of the Avon River (Mulcahy and Hingston, 1961), to the most extensive divides of the Great Plateau. While the laterites of some of the younger landforms, particularly those of the Swan Coastal Plain, may be regarded as forming today in the sense of meeting the classical environmental requirements for laterite formation postulated by Prescott and Pendleton (1952), those of the older landforms clearly cannot, being either in unsuitable topographic situations or in semi-arid and arid climatic conditions, or both. Further, in all but highest rainfall areas the extremely leached and weathered pallid zones now contain an appreciable store of soluble salts (Dimmock *et al.* in prep.) so that leaching conditions are clearly less effective than in the past.

Physiography

Figure 1 shows some of the main physiographic features of south western Australia, to which the soil pattern may be related.

The Darling Scarp marks the western margin of the shield and Great Plateau, beyond which the Precambrian rocks are buried by a considerable thickness of sediments of the Perth Basin and Swan Coastal Plain. To the south the shield slopes gently into the Southern Ocean, with a discontinuous, thin veneer of Tertiary and Recent sediments. The section (Fig. 1, ABC) shows clearly the relatively high relief and elevation of the Darling Range, regarded by King (1962) as a marginal upwarping of the shield rocks. It is separated from the gradually rising plateau levels of the interior by a belt of

lower country showing partial coincidence with an important zone of seismic activity, the "Yandanooka/Cape Riche Lineament" (Everingham, 1968).

A little further inland is another important, but not so obvious physiographic feature, the Meckering Line (Mulcahy, 1967), which marks a striking change in the drainage pattern. Inland of it the drainage is sparse, open and sluggish, with chains of salt lakes in the main trunk valleys. A large proportion of the westward-flowing lake chains joins the headwaters of the Swan-Avon system, off the mouth of which is a prominent submarine canyon on the continental shelf (Von der Borch, 1968). Most of the remainder reaches the Moore and the Blackwood Rivers (Bettenay and Mulcahy, 1972). A major continental divide separates these systems from a generally eastward trending one draining to the Nullarbor Plain and Great Victoria Desert in the interior. In most years under the present climatic regime the system as a whole does not flow, acting as a sump in which the salts accumulate in the playa lakes. In exceptionally wet years, however, it becomes functional, and flowing water flushes out the accumulated salts into the downstream drainage lines (Fig. 1).

Downstream of the Meckering Line in the west, the drainage lines form a closer network, have steeper gradients, are more sharply incised, and thus form a much more effective drainage system functional in all normal winters. Depth of incision of the streams increases progressively, with a change from shallow flat floored valleys to deep V-shaped valleys where they issue from the Darling Scarp.

Thus the zone marginal to the Meckering Line, particularly in the Darling Range, is one of considerable relief relative to that inland of it. Nevertheless, many of the more extensive divides in the marginal zone are upland areas of low relief, with features such as lakes and swamps associated with sluggish drainage lines comparable with those inland. Their broad, flat-floored valleys characteristically have grey sandy valley fills, and some are known to have sedimentary sequences of considerable thickness, such as the Kirup Conglomerate (Hobson and Matheson, 1949), or the Permian sediments of the Collie Basin (Lord, 1952). While it is tempting to regard these features collectively as dismembered remnants of the old drainage systems now preserved only in the interior, such an interpretation is undoubtedly too simple. It could not account, for example, for the Kirup Conglomerate which, with its smoothly rounded cobbles in a finer sandy and clayey matrix, is obviously a deposit resulting from a high energy means of transport. A conclusion must await further investigations in a field of enquiry as yet virtually untouched.

Laterites, superficial deposits and soils

Distribution of lateritic materials

Figure 2 illustrates the broad regional distribution of lateritic and other soil materials in south western Australia, based largely on Northcote *et al.* (1967).

The map distinguishes between the low level laterites of the Swan Coastal Plain, the "ironstone gravels" or bauxitic laterites of the Darling Range and adjacent high rainfall areas to the south, and the extensive "sand and gravel plains" inland and to the north. All may be classed as laterites in that they have surface horizons of accumulation of iron oxides, frequently, but not invariably overlying deeply weathered kaolinized country rock, the pallid zone (Walther, 1915). The Darling Range laterites, together with the sandplains, are associated with Jutson's (1914) Old Plateau and Woolnough's (1918) Darling Peneplain, but the Section ABC of Fig. 2 shows the considerable relief of the lateritic surfaces of the Darling Range—only inland of the Meckering Line does the low relief traditionally postulated for the lateritized peneplain become apparent. In both the Darling Range and the sandplain areas the lateritic pallid zones are most widespread and deepest. They may be up to 30 metres in thickness, beneath the floors of the trunk valleys of the inland drainage systems, while they are much shallower beneath the sandplains of the divides (Bettenay *et al.*, 1964). Downstream of the Meckering Line deepest weathering is probably associated with the older valley forms of the low relief upland divides.

On the Swan Coastal Plain, west of the Darling Scarp, deep pallid zones are common on the older piedmonts, but associated ferruginous duricrusts are less frequent, except near the foot of the scarp on slightly elevated spurs corresponding with the Ridge Hill Shelf described by Prider (1948).

It is evident (Fig. 2) that areas free or almost entirely free of lateritic materials are restricted, being confined to the deeply entrenched valleys of the downstream sections of streams as they issue from the Darling Range, or further inland, to the entrenchment of streams associated with the Yandanooka/Cape Riche Lineament. High points above the general level, such as the Stirling Range, and a number of others too small to show because of scale, are also almost completely free of laterite.

The principal remaining area of the map (Fig. 2) shown as "Dissected Laterites" is one of considerable complexity in terms of landforms and soils. The small divides and valley side spurs tend to be capped with lateritic materials, and bounded by prominent, erosionally-active scarps or breakaways, the long pediment slopes below them being underlain by pallid zones of the truncated laterites. These features are best developed immediately west of the Meckering Line, where available relief is greatest, while rainfall is still low, less than 500 mm per annum. Towards the coast, and in higher rainfalls, these typically arid-zone landforms are replaced by more gently inflected concavo-convex slopes associated with less active erosion. Only adjacent to sharply incised streams and on the steeper valley sides are fresh rock materials locally exposed.

Superficial deposits

Many of the lateritic materials mapped in Fig. 2 are detrital. Those of the high relief areas of the Darling Range often consist of fragments of ironstone, and sometimes fresh rock, recemented with skins of iron oxide (Mulcahy, 1961). These materials may extend downslope as colluvial sheets overlying a variety of substrates, including relatively fresh country rock (Mulcahy *et al.*, 1972).

The sandplain materials too have been shown to be colluvial deposits of local origin derived largely from the ferruginous duricrust of pre-existing laterites (Mulcahy, 1961; Brewer and Bettenay, 1973). Further, they are multiple deposits, not all of the same age; some, the most extensive, carrying undifferentiated sandy yellow earth soils, are clearly very young, while others are older, and have developed segregations of iron oxide which harden on exposure. Both forms, the undifferentiated younger deposits overlying the older, may be found capping classical lateritic residuals bounded by breakaways (Mulcahy, 1964). It follows that the surfaces of such rcsiduals cannot be uncritically accepted as any kind of time marker or datum.

Colluvial and alluvial deposits derived from fresh rock outcrop are important though limited in extent. They are confined principally to the valley sides and floors, and to limited areas on the Swan Coastal Plain, where they give rise to the more fertile soils in comparison with those derived from lateritic materials. Fresh colluvial deposits are also occasionally found on upland divides where rock outcrops are exposed by the stripping of the pre-existing laterites to form the sandplain deposits downslope.

Aeolian activity and dune formation are not common on the sandplain surfaces, except perhaps in the arid interior, in the east of the area considered. There is some aeolian activity associated with the drainage lines. Bettenay (1962) has described the formation of "lake parna", a silty, calcareous and saline deposit blown out of the salt lake chains, which may account for the extensive calcareous soils shown in Fig. 2. They may, on the other hand, be due in part to the more extensive occurrence of basic and ultrabasic rocks in the eastern goldfields. Aeolian sands blown out of stream channels have been reported by Northcote *et al.* (1967) from the higher rainfall areas. Windblown coastal beach dunes are almost continuous, particularly on the west coast, and show age sequences related to Pleistocene sea levels (Fairbridge, 1954; McArthur and Bettenay, 1960). Aeolianite limestone dune and beach rocks, the result of leaching of the original calcareous sands and consolidation of the lower layers by deposition of carbonates, are prominent in the coastline, offshore reefs and coastal islands (Fairbridge, 1953).

Soils

Only a brief outline of the nature of the soils, related to the foregoing account of the geomorphology and superficial deposits, can be given here. A considerable amount of further information within this framework may be extracted from the published Atlas of Australian Soils (Northcote *et al.*, 1967), with careful study of the map legend and the accompanying Memoir. Reference to areas of detailed study on which this account is based is also given where relevant.

Relatively little has been published on the *Darling Range soils*, apart from a broad scale study by Mulcahy *et al.* (1972). Smith (1951a, 1951b) has published accounts of the rather similar patterns in the Donnybrook Sunkland and towards the south coast. In the latter of these, on the Frankland-Gordon river valley, he drew attention to the sequential change of valley form from the broad valleys of the inland areas to the more sharply incised forms downstream. The dominant soils are, of course, the lateritic gravels (KS-Uc4.1 and KS-Uc4.2)*, consisting of up to 5 metres or more of ironstone gravels in a yellow sandy matrix and the related lateritic podsolics (Dy3.61) with ironstone gravels in a sandy surface overlying a mottled yellow-brown clay subsoil. These materials frequently overlie a pallid zone up to 30 metres or more in thickness. Massive ironstone pavements are common on ridgetops and occasionally on slopes. It is worth emphasizing that, apart from more extensive divides, there is some considerable relief (Fig. 2), with slopes up to 8°. In general, the gravels tend to become finer downslope, sometimes grading into sandy yellow earths (Gn2.21) in the lowest positions. The mid-slope gravels are those currently being mined as bauxite. The broader valleys of the more extensive divides carry grey sands over ironstone gravels (Uc2.3) or solonetzic profiles (Dg3.81), both overlying deep pallid zones. Further downstream the sides of the more incised valleys have a range of soils including red and yellow podsolics (Dr2.21 and Dy3.21) and red and yellow earths (Gn2.14, and Gn2.21).

The complex soil pattern of the zone of *dissected laterites* has been described by Mulcahy and Hingston (1961), and Bettenay and Hingston (1964). West of the Meckering Line the truncated laterites and limited exposures of fresher rock give rise to a range of solodic and podsolic soils (Dy3.82 and Dy3.81) and some red-brown earths with generally neutral reaction trends (Dr2.22). Further inland, with longer, gentler slopes and lower rainfall, reaction trends of the red-brown earths become alkaline (Dr.2.33).

The soils of the predominantly *sandplain areas* and the associated broad valleys, forming the larger part of the agricultural area of Western Australia, have been described by Bettenay and Hingston (*loc. cit.*) for an area representative of the shield and by Churchward (1970) where they are extensively developed over the Jurassic sediments, often sandstones,

*Notation in parentheses after names of great soil groups refers to the classification of Australian soils by Northcote 1971.

flanking the shield to the north. The sandplain soils are predominantly sandy yellow earths (Gn2.21) with some sands over ironstone gravels (Uc5.22). The limited areas of fresher rock outcrop on the valley sides, and the alluvial deposits of the valley floors carry sodic brown soils (Dr2.33) with calcareous subsoils. Both upland and valley floor are, however, underlain by lateritic pallid zones, deepest in the latter situation, where the ground water is similar in composition to sea water, though it may exceed it in the concentration of salts. Thus the relatively fresh materials of the soils of the valley floors, which are calcareous and alkaline, overlie acid and saline substrates. Bettenay *et al.* (1964) calculate that 90% of the salts stored in the landscape are in these valley ground waters, and only a small proportion in the rather more obvious playa lakes.

The aeolian lake parnas (Bettenay, 1962) give rise to the silty, saline calcareous earths (Gc1.12 and Gc1.22) adjoining the salt lakes, usually on the eastern or south eastern (downwind) margins. The greater inland extent of these soils (Fig. 2) may be due to the greater extent of the lakes as a source area, or alternatively to a greater relative abundance of fine textured basic and ultrabasic rocks.

The Swan Coastal Plain provides two important age sequences of soils covering a period extending as far back as the Mindel-Riss interglacial (McArthur and Bettenay, 1960) or perhaps beyond it. One is developed on the coalescing piedmonts near the foot of the scarp, and the other on the wind blown sands of the coastal areas.

The older, and most widespread, alluvial deposits have been lateritized, but also have been extensively stripped, so that the dominant soil is a meadow podsolic (Dy5.81) consisting of a sandy surface over a poorly structured subsoil clay of low permeability developed in the lateritic pallid zone. Younger deposits, in the form of the terraces incised in these older materials, or of alluvial fans laid over them, carry a sequence of red and yellow podsolics (Dr2.81 and Dy2.21) and of undifferentiated soils on the relatively fresh youngest deposits. Thus McArthur and Bettenay *(loc. cit.)* were able to establish the age relationships of the soils by the frequently observed and invariable order of superposition of the deposits.

The youngest beach dune systems are at the present coastline, consisting of a highly calcareous shell sand (Uc1.1). Inland they are succeeded by slightly podsolized yellow sands (Uc4.2), almost entirely quartz, but with some local areas where heavy minerals are abundant. The yellow sands are invariably underlain by aeolianite rock which, however, extends beyond them far to the west, underlying the present day dunes at the coast and on the offshore islands, so that the system must have been at one time far more extensive. The oldest system furthest inland has now lost its dune morphology, and is of low relief compared with the younger systems nearer to the coast. Its soils are extremely leached and podsolized white quartz sands with B horizons of iron and organic matter accumulation (Uc2.3). They are important intake areas for the coastal plain aquifers and are underlain by fresh ground waters at shallow depths.

Discussion and conclusion

The account of soils and landforms given here is necessarily brief and incomplete, partly because a comprehensive treatment is impossible in a short paper, and partly because of gaps in our knowledge. Similarly, a discussion of the significance of the data presented must also be limited, since it would involve consideration of a large number of aspects, ranging from fundamental questions of soil and landscape development to practical and applied problems as diverse as minerals exploration, agricultural technology, or land use planning. Some of the more important are briefly considered below.

Landscape development

Preoccupation with questions of the age and development of laterite is a common and understandable characteristic of discussions of this topic in Western Australia. One or perhaps two periods of formation in the past are assumed (e.g., Prider, 1966), and thus the possibility of using a lateritized surface as a time marker is raised.

The evidence reviewed here shows that well-developed, deep laterite profiles may be found on surfaces as young as (early?) Pleistocene on the Swan Coastal Plain, where the process may still be continuing. They are most widespread on the older landscape elements of the Old Plateau, which Johnstone *et al.* (1973) considered to have been established in its present form by the mid-Cretaceous. The older laterites, except in the highest rainfall areas, now contain appreciable quantities of soluble salts in their pallid zones indicating that the necessary leaching conditions for their development are no longer operative. These facts, together with the detrital and transported nature of many lateritic materials, makes their use as a stratigraphic marker suspect, though they are, of course, likely to be preserved where erosional forces are least effective, i.e., on gentler slopes and in well vegetated higher rainfall areas.

Age of landscape is much more likely to be indicated by a combination of landscape characteristics rather than the occurrence of a single characteristic such as laterite. These would include low relief, widespread deep weathering, ineffective drainage systems, and widespread retention within the landscape of weathering products and sediments derived from them. These are the conditions found most extensively inland of the Meckering Line.

Tectonics are, of course, an important factor in landscape development. In this connection the correspondence of entrenchment of the drainage and greater relief with the Yandanooka/Cape Riche lineament (Fig. 2) is noteworthy, and is reflected in the soil pattern with

the exposure of fresher rocks as soil parent materials and the truncation and dissection of the lateritic profiles.

Ecological implications

Southwestern Australia is probably unique in its great extent of deeply weathered and leached soil materials, and consequent extremely low levels of natural soil fertility. An account of the natural vegetation adapted to these conditions is given elsewhere in this volume. Isolation by climatic barriers, particularly that of aridity, is often invoked to account for some of the unique features and speciation in the Western Australian fauna and flora. An additional factor may be the formidable barrier presented by the great extent of infertile sandplain soils on the major continental and regional drainage divides shown in Fig. 2.

Minerals exploration

The great extent of deep weathering and of superficial deposits, particularly the sandplains, not directly related to the underlying geology, obviously makes location of ore bodies difficult. In many areas the nature of the surface materials is very poorly understood; for example, the mallisols of the eastern goldfields, which may be either aeolian deposits blown from the lakes, or formed directly from ultrabasic rocks.

The old drainage lines of the interior and possible remnants of them in marginal areas are also of importance in this context, since they drain catchments now deeply weathered, including those in which ore bodies have been discovered. Deep leads are well known in the eastern goldfields (e.g., Campbell, 1906), and have been described from the extreme south west at Greenbushes, where some of the tin mined is alluvial (Hobson and Matheson, 1949). The study of these and other fragmented remnants of old drainage and sedimentary systems shown in Fig. 1 may lead to further discoveries of economic value.

Agricultural development

Early pastoral and agricultural development was confined to the more fertile non-lateritic soils of the valley floors and flanking rock outcrops, where, too, water supplies and natural grazing for stock were more readily available.

With the identification of the nutrient deficiencies, including the minor elements zinc, copper, cobalt and molybdenum, which limit crop and pasture establishment on the lateritic soils, and with the growth of a fertilizer technology, agricultural development has been, until recently, proceeding at an extremely rapid rate on these soils. This has been possible, however, only where rainfall is adequate, so that inland of about the 250 mm isohyet, where sandplains are extensive, neither farming nor grazing is possible, due to the low nutritive value of the native vegetation and the frequent occurrence of poisonous legumes. Only further inland again, in the vicinity of the eastward draining salt lake systems, does pastoral activity become possible.

Hydrology

The store of soluble salts in the widespread lateritic pallid zones (Dimmock *et al.* in prep., Bettenay *et al.*, 1964) presents a peculiar hydrologic problem. It is continually being replenished by atmospheric accession in rainfall at rates of the order of 200 kg/ha NaCl in high rainfall areas of the Darling Range, falling off rapidly inland (Teakle, 1937, Hingston, 1958). Its retention within the landscape is apparently a matter of an extremely delicate balance. This is easily disturbed by clearing of the perennial native vegetation with its deep rooting systems and growth habit persisting into the dry summer season and its replacement by short lived shallow rooting, winter growing, annual crops and pastures. As a result evaporative losses of water from surface soils decrease and ground water recharge increases, with increased discharge of water and salts in streams. Agricultural development on sandplain areas inland of the Meckering Line has thus increased the frequency with which the salts from the lake chains are flushed into the headwaters of the major rivers, so increasing the salt content of the latter. Where drainage systems are ineffective the salts accumulate in the valleys, so that agricultural development has led to soil salinity in those situations (Lightfoot *et al*, 1964). Peck and Hurle (in press) in a study of water and salt balances of farmed and forested areas show that catchments with average annual rainfalls less than 1000 mm/annum, if extensively cleared, become unsuitable for damming for water supply purposes due to the salinity of the water. Their analysis also shows that where the salt balance is so disturbed the achievement of a new equilibrium at an acceptably low level of salinity may take times of the order of tens, or more commonly, hundreds of years.

Land use planning

Development of different forms of land use in southwestern Australia has proceeded very largely on an *ad hoc* basis. Gold, and later other minerals, were mined where most readily accessible, and when technological development and growth of world demands made them transportable and marketable.

Agricultural development has proceeded similarly, where the current state of farming technology permitted, and in response to the fluctuating demands of overseas markets. While farming has built up soil fertility by importing phosphate and through the use of legume nitrogen, it has been at the cost of considerable effects on water supply and quality. Only forestry, with its traditional attachment to the policies of sustained yield, under management by a single State authority, has developed on a conservative basis. Even so, the native hardwood forest today compares badly with the few isolated areas within it still untouched by the timber fallers and sawmillers. But the extent to which the forest has been preserved is the extent to which the delicate hydrologic balance,

on which the water supplies of the south-west depend, has been conserved.

As the population and industrial and mining development increases in the south west of Western Australia, with its relatively equable climate, competing demands on the agricultural, forestry, mineral, public amenity and water supply resources especially in the Darling Range, will increase. Of these, the last is most likely to be limiting, so that its conservation is of highest priority.

A continuing objective of agricultural and forestry research should be the restoration of the hydrologic balance through the strategic deployment of land-use systems more efficient in the use of water, since its misuse and wastage through inability to utilize the abundant winter rainfall is the root cause of water supply and salinity problems.

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